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(54) **METHOD FOR MAKING SEMICONDUCTING SINGLE WALL CARBON NANOTUBES**

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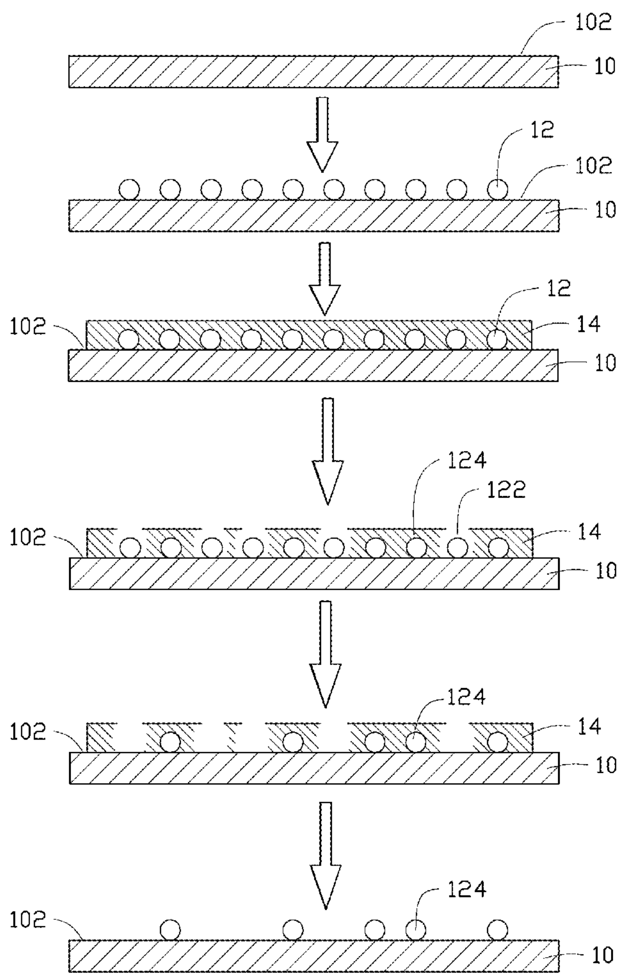
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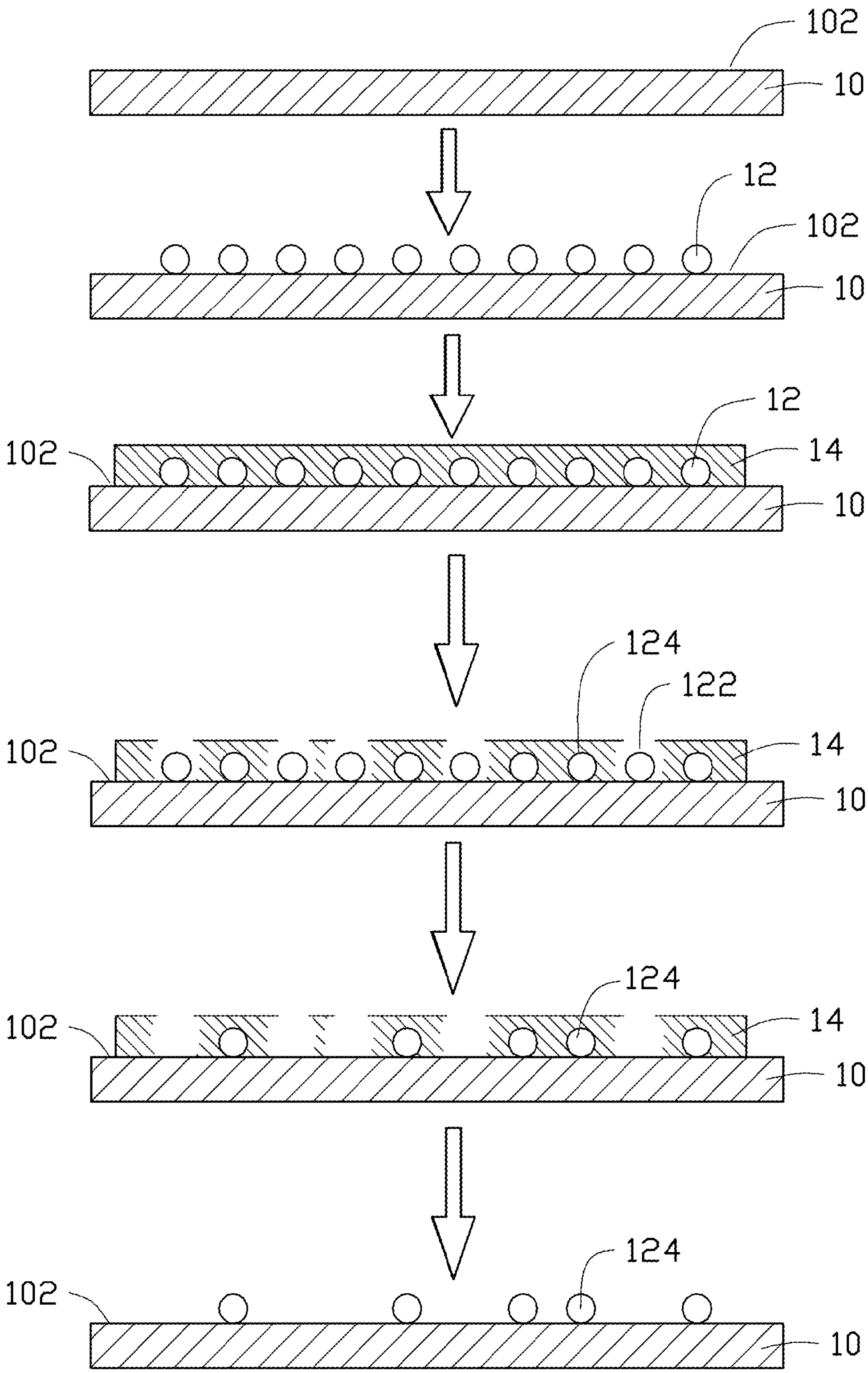
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(57) **ABSTRACT**

A method for making semiconducting single walled carbon nanotubes (SWCNTs) includes providing a substrate. A single walled carbon nanotube film including a plurality of metallic SWCNTs and semiconducting SWCNTs is located on the substrate. A macromolecule material layer is located on the single walled carbon nanotube film to cover the single walled carbon nanotube film. The macromolecule material layer, the single walled carbon nanotube film and the substrate are placed in an environment filled with electromagnetic waves. The macromolecule material layer covering the plurality of the metallic SWCNTs is melted or decomposed to expose the plurality of metallic SWCNTs. The metallic SWCNTs and the macromolecule material layer covering the semiconducting SWCNTs are removed.





102
10
12
102
10
12
102
14
10
124
122
102
14
10
124
102
14
10
124
102
10

FIG. 1

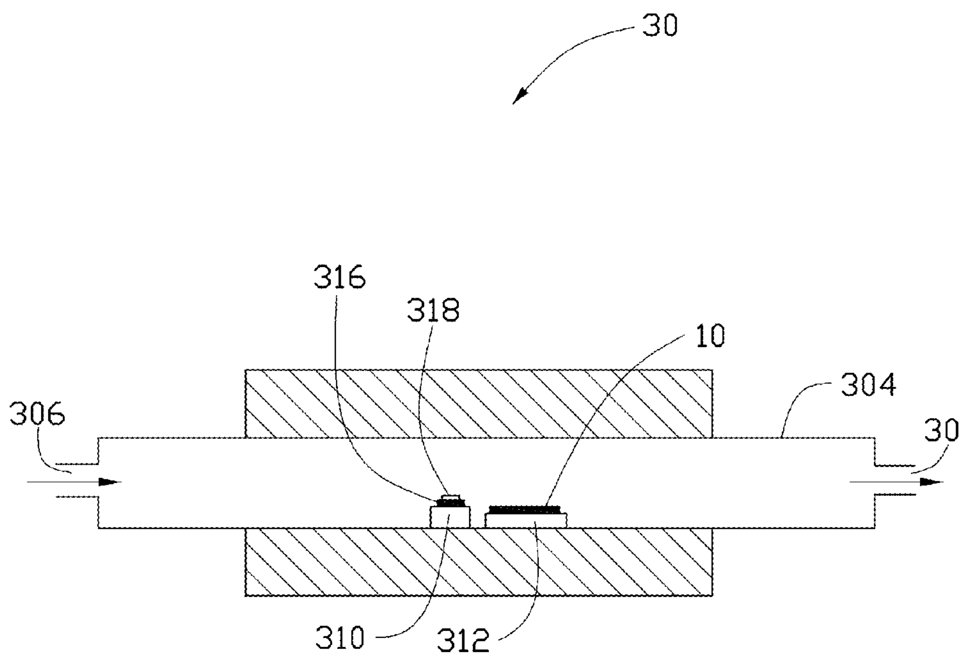


FIG. 2

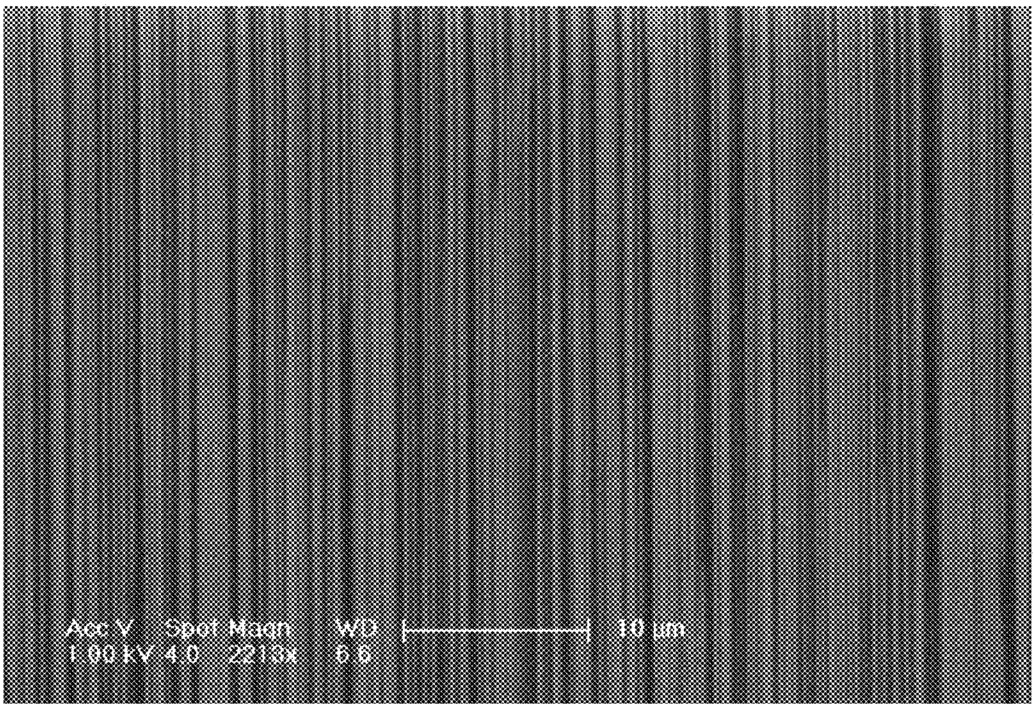


FIG. 3

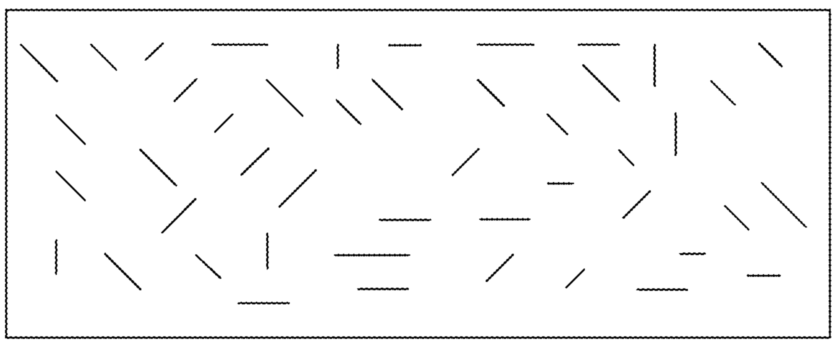


FIG. 4

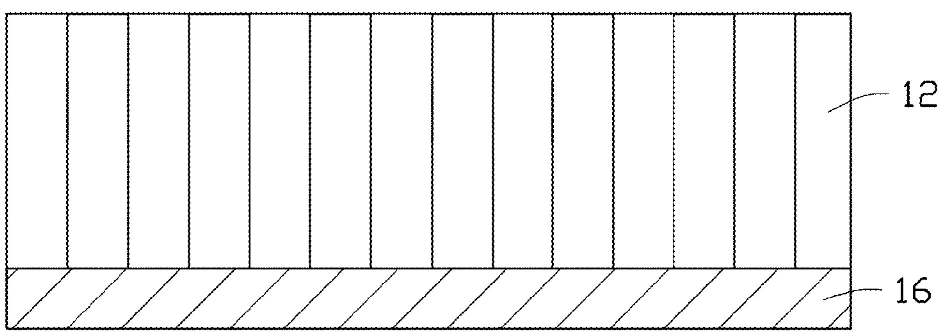


FIG. 5

METHOD FOR MAKING SEMICONDUCTING SINGLE WALL CARBON NANOTUBES

RELATED APPLICATIONS

[0001] This application claims all benefits accruing under 35 U.S.C. §119 from China Patent Application No. 201210075759.7, filed on Mar. 21, 2012, in the China Intellectual Property Office. This application is related to commonly-assigned application entitled "METHOD FOR MAKING SEMICONDUCTING CARBON NANOTUBES," concurrently filed (Atty. Docket No. US45169). Disclosures of the above-identified applications are incorporated herein by reference.

BACKGROUND

[0002] 1. Technical Field

[0003] The present application relates to a method for making semiconducting single walled carbon nanotubes.

[0004] 2. Discussion of Related Art

[0005] Single walled carbon nanotubes (SWCNTs) may be metallic or semiconducting, and may have varying diameters and lengths. Applications using SWCNTs may be improved if SWCNTs of uniform conductivity, such as all semiconducting SWCNTs or all metallic SWCNTs, are provided. Accordingly, a method for making semiconducting SWCNTs is desired.

[0006] A method for making semiconducting SWCNTs involves destruction of metallic SWCNTs by electric current (See, Collin P. et al., Science, 2001, 292, 706). A principle of this method is that semiconducting SWCNTs can be turn "off" by applying a gate voltage. It is possible to burn out metallic SWCNTs by application of a high source-drain voltage in the presence of oxygen. However, when a current flows through the metallic SWCNTs, Joule heat generated by the metallic SWCNTs might inadvertently burn out the adjacent semiconducting SWCNTs.

[0007] What is needed, therefore, is to provide a method for making semiconducting SWCNTs that can overcome the above-described shortcomings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] Many aspects of the embodiments can be better understood with references to the following drawings. The components in the drawings are not necessarily drawn to scale, the emphasis instead being placed upon clearly illustrating the principles of the embodiments. Moreover, in the drawings, like reference numerals designate corresponding parts throughout the several views.

[0009] FIG. **1** is a schematic process flow of one embodiment of a method for making semiconducting SWCNTs.

[0010] FIG. **2** is an illustration of a growing device for making a single walled carbon nanotube film.

[0011] FIG. **3** shows a scanning electron microscope image of the single walled carbon nanotube film manufactured by the growing device of FIG. **2**.

[0012] FIG. **4** is a schematic view of another embodiment of the single walled carbon nanotube film according to FIG. **1**.

[0013] FIG. **5** is a schematic view of one embodiment of an electrode located on one side of the single walled carbon nanotube film of FIG. **2**.

DETAILED DESCRIPTION

[0014] The disclosure is illustrated by way of example and not by way of limitation in the figures of the accompanying drawings in which like references indicate similar elements. It should be noted that references to "an" or "one" embodiment in this disclosure are not necessarily to the same embodiment, and such references mean at least one.

[0015] Referring to FIG. **1**, a method for making semiconducting SWCNTs of one embodiment includes steps of:

[0016] (S**1**), providing a substrate **10** having a first surface **102**;

[0017] (S**2**), placing a single walled carbon nanotube film **12** on the first surface **102** of the substrate **10**, wherein the single walled carbon nanotube film **12** includes a plurality of metallic SWCNTs **122** and a plurality of semiconducting SWCNTs **124**;

[0018] (S**3**), applying a macromolecule material layer **14** on the single walled carbon nanotube film **12** to cover each of the plurality of metallic SWCNTs **122** and each of the semiconducting SWCNTs **124**, wherein the macromolecule material layer **14**, the single walled carbon nanotube film **12** and the substrate **10** form a compound;

[0019] (S**4**), exposing the plurality of metallic SWCNTs **122** by melting or decomposing the macromolecule material layer **14** in an environment filled with electromagnetic waves;

[0020] (S**5**), removing the plurality of metallic SWCNTs **122**; and

[0021] (S**6**), removing the macromolecule material layer **14** to obtain the plurality of semiconducting SWCNTs **124**.

[0022] In the step (S**1**), the substrate **10** can be a substantially flat and smooth silicon substrate, such as a P-type silicon wafer, an N-type silicon wafer or a silicon wafer formed with an oxidized layer thereon. The substrate **10** can also be made of polymer or quartz. The substrate **10** has a high melting point, and the melting point of the substrate **10** can be greater than or equal to 600° C. In the first embodiment, a P-type silicon wafer is used as the substrate **10**.

[0023] In the step (S**2**), the single walled carbon nanotube film **12** includes a plurality of SWCNTs including a plurality of metallic SWCNTs **122** and a plurality of semiconducting SWCNTs **124**. A positional relationship of the metallic SWCNTs **122** and the semiconducting SWCNTs **124** is arbitrary. The plurality of SWCNTs is parallel to a surface of the single walled carbon nanotube film **12** and the first surface **102** of the substrate **10**. In the single walled carbon nanotube film **12**, two adjacent SWCNTs are not in contact with each other, to prevent a heat of the metallic SWCNTs from burning out adjacent semiconducting SWCNTs. A distance between two adjacent SWCNTs can be greater than or equal to 10 nanometers. The plurality of SWCNTs can have the same length and be parallel to each other. The plurality of SWCNTs can have different lengths and not be parallel to each other. In one embodiment, the plurality of SWCNTs has the same length and is parallel to each other, the distance between two adjacent SWCNTs is 500 nanometers. A thickness of the single walled carbon nanotube film **12** can be in a range from about 0.5 nanometers to about 10 nanometers. In one embodiment, the thickness of the single walled carbon nanotube film **12** is in a range from about 0.5 nanometers to about 5 nanometers.

[0024] Referring to FIG. **2**, a method for making the single walled carbon nanotube film **12** of one embodiment includes steps of:

[0025] (S**21**), providing a growing device **30** including a fixing supporter **310** and a rotatable supporter **312**;

[0026] (S**22**), providing a growing substrate **316** and the substrate **10**, wherein a catalyst layer **318** is formed on a surface of the growing substrate **316**;

[0027] (S**23**), placing the growing substrate **316** on the fixing supporter **310**, and placing the substrate **10** on the rotatable supporter **312**;

[0028] (S**24**), introducing a carbonaceous gas to grow a plurality of SWCNTs along a gas flow direction;

[0029] (S**25**), stopping introducing the carbonaceous gas, the plurality of SWCNTs formed on the first surface **102** of the substrate **10** is parallel to each other; and

[0030] (S**26**), changing the growing substrate **316**, and the single walled carbon nanotube film **12** is formed on the first surface **102** of the substrate **10**.

[0031] In the step (S**21**), the reacting room **304** has a gas inlet **306** and a gas outlet **308**. A rotatable supporter **312** disposes in the reacting room **304**. A fixing supporter **310** disposed in the reacting room **304** is closer to the gas inlet **306** than the rotatable supporter **312**. A distance between the rotatable supporter **312** and the fixing supporter **310** is less than 1 micrometer. The rotatable supporter **312** is lower than the fixing supporter **310**. The rotatable supporter **312** can rotate in the horizontal plane arbitrarily.

[0032] In the step (S**22**), the catalyst layer **318** includes a layer of monodisperse catalyst. The method of forming the catalyst layer **318** depends on the material of the monodisperse catalyst.

[0033] While the catalyst is made of iron (Fe), cobalt (Co), nickel (Ni), or any alloy thereof, the process of forming the catalyst layer **318** on the growing substrate **316** includes the following substeps of: (a**1**) depositing a layer of monodisperse catalyst on the growing substrate **316**; (a**2**) patterning the layer of monodisperse catalyst to form a catalyst layer **318** which is patterned. The method of depositing the catalyst layer **318** is selected from the group comprising of physical vapor deposition, chemical vapor deposition, coating and plating. The thickness of the catalyst layer **318** approximately ranges from 1 nanometer to 3 nanometers. Due to the thickness of the catalyst layer **318** being small, the catalyst materials in the catalyst layer **318** forms a plurality of monodisperse catalyst particles.

[0034] If the catalyst layer **318** is made of monodisperse solution of metal or metal-salt, the process of forming the catalyst layer **318** on the growing substrate **316** includes the following substeps of: (a**1'**) applying a monodisperse solution onto the surface of the growing substrate **316** to form a layer of monodisperse solution; (a**2'**) drying the monodisperse solution layer to form a catalyst layer **318**. The step (a**1'**) can be replaced by dipping the growing substrate **316** into the monodisperse solution. It could avoid the catalyst materials to gather together by using monodisperse solution to form the catalyst layer **318**. Therefore, the catalyst layer **318** includes a plurality of monodisperse catalyst particles. The monodisperse solution of metal-salt can be selected from the group comprising a solution of $Fe(NO_3)_3$ and water, solution of $CuCl_2$ and water, solution of $FeCl_3$ and water, solution of $Fe(NO_3)_3$ and ethanol, solution of $CuCl_2$ and ethanol, and solution of $FeCl_3$ and ethanol. The monodisperse solution of metal is selected from the group comprising a solution of Fe—Mo and n-octane, solution of Fe—Co and n-octane, solution of Fe—Ru and n-octane, solution of Fe—Mo and hexane, solution of Fe—Co and hexane, solution of Fe—Ru and hexane, solution of Fe—Mo and ethanol, solution Fe—Co and ethanol, and solution of Fe—Ru and ethanol. In one embodiment, the catalyst layer **318** is formed by a solution of $Fe(NO_3)_3$ and ethanol.

[0035] In the step (S**23**), while placing the growing substrate **316** on the fixing supporter **310**, it is necessary to make sure the catalyst layer **318** faces up. The growing substrate **316** and the substrate **10** are made of high melting materials. The melting point of the growing substrate **316** and the substrate **10** is above the growing temperature of the single walled carbon nanotube film. The shape and area of the growing substrate **316** and the substrate **10** is arbitrary.

[0036] The growing substrate **316** can be a rectangle. In one embodiment, the growing substrate **316** is a silicon strip. The length of the growing substrate **316** is 10 centimeters and the width of the growing substrate **316** is 1 millimeter. The growing substrate **316** can be made by the steps of forming a catalyst layer **318** on a large wafer, and then cutting the large wafer into a number of silicon strips of predetermined size. The substrate **10** can be a square. The length of side of the substrate **10** approximately ranges from 1 centimeter to 10 centimeters. Also, the substrate **10** can be a network, such as copper wire mesh. In one embodiment, the substrate **10** is a 4-inch wafer.

[0037] The step (**24**) includes the following substeps of: (b**1**) introducing a protective gas into the reacting room **304** to evacuate the air in the reacting room **304**; (b**2**) heating the reacting room **304** up to growing temperature of the SWCNTs; and (b**3**) introducing a carbonaceous gas to grow the SWCNTs.

[0038] In the step (b**1**), the protective gas is selected from the group comprising of nitrogen (N_2) gas and noble gas. In one embodiment, the protective gas is argon (Ar) gas.

[0039] In the step (b**2**), the growing temperature of the SWCNTs ranges approximately from 800 degrees to 1000 degrees. It is to be understood that the growing temperature varies with the carbonaceous gas. In one embodiment, the carbonaceous gas is ethanol, so the growing temperature of the SWCNTs ranges approximately from 850 degrees to 950 degrees. If the carbonaceous gas were methane, the growing temperature of the SWCNTs would range approximately from 950 degrees to 1000 degrees.

[0040] In the step (b**3**), the carbonaceous gas is hydrocarbon with active chemical properties. The carbonaceous gas can be selected from the group comprising of ethanol, ethane, methane, and combinations thereof. In one embodiment, the carbonaceous gas is ethanol or methane. The flux of the carbonaceous gas ranges approximately from 5 to 100 milliliter per minute. An additional carrier gas such as hydrogen, can be also introduced into the reacting room **304** with the carbonaceous gas. The flux ratio of the carbonaceous gas and the carrier gas ranges approximately from 1:1 to 1:3.

[0041] After introducing the carbonaceous gas into the reacting room **304**, it starts to grow carbon nanotubes under the effect of the catalyst. One end (i.e., the root) of the carbon nanotubes is fixed on the growing substrate **316**, and the other end (i.e., the top/free end) of the carbon nanotubes grow continuously. The density of the carbon nanotubes is low due to the catalyst layer **318** including a plurality of monodisperse catalyst grain. Therefore, a part of the carbon nanotubes grow into SWCNTs. Because the fixing supporter **310** disposed in the reacting room **304** is near the gas inlet **306**, the SWCNTs float above the substrate **10** with the roots of the SWCNTs still sticking on the growing substrate **316**, as the carbon-

aceous gas is continuously introduced into the reacting room **304**. The mechanism of growing SWCNTs is called "kite-mechanism." The length of the SWCNTs depends on the growing time. In one embodiment, the growing time approximately ranges from 10 minutes to 30 minutes. The length of the SWCNTs approximately ranges from 1 centimeter to 30 centimeters.

[0042] In the step (S**25**), after cutting off the supply of the carbonaceous gas into the reacting room **304**, the SWCNTs stop growing and land on the substrate **10**. The SWCNTs fall down onto the substrate **10** parallel and separately due to the gravity and are allowed to cool. In order to avoid oxidation of the SWCNTs, the protective gas should be continuously fed into the reacting room **304** until the temperature of the reacting room **304** is cooled down to room temperature. Furthermore, the single walled carbon nanotube film **12** is cut off from the growing substrate **316**.

[0043] In the step (S**26**), changing the growing substrate **316** can be carried out by providing a new one of the growing substrate **316** with the catalyst layer **318** or recycling the original growing substrate **316**. The original growing substrate **316** is recycled by cleaning the original growing substrate **316** and forming a new catalyst layer **318** thereon. More SWCNTs can fall on to the first surface **102** of the substrate **10** to form the single walled carbon nanotube film **12** by repeating steps (S**24**) and (S**25**) as often as desired.

[0044] Referring to FIG. **3**, the single walled carbon nanotube film **12** has a plurality of SWCNTs parallel to each other. The plurality of SWCNTs has the same length of 100 micrometers, the distance between two adjacent SWCNTs is 500 nanometers. The SWCNTs in the single walled carbon nanotube film **12** connect to each other by van der Waals attractive force therebetween, thus, the single walled carbon nanotube film **12** is a free-standing structure.

[0045] The term "free-standing" includes, but not limited to, the single walled carbon nanotube film **12** that does not have to be supported by a substrate. For example, the single walled carbon nanotube film **12** which is free-standing can sustain the weight of itself when it is hoisted by a portion thereof without any significant damage to its structural integrity. So, if the single walled carbon nanotube film **12** which is free-standing is placed between two separate supporters, a portion of the free-standing single walled carbon nanotube film **12**, not in contact with the two supporters, would be suspended between the two supporters and yet maintain film structural integrity.

[0046] It is understood, the single walled carbon nanotube film **12** can be formed by coating a solution of SWCNTs on the first surface **102** of the substrate **10**. At the same time, the SWCNTs can have different lengths and not be parallel to each other. It is necessary to make sure two adjacent SWCNTs are not in contact with each other, as shown in FIG. **4**.

[0047] In the step (S**3**), the macromolecule material layer **14** can enclose each of the plurality of metallic SWCNTs and each of the plurality of semiconducting SWCNTs. The space between each two adjacent SWCNTs of the plurality of SWCNTs is filled with material of the macromolecule material layer **14**. The macromolecule material layer **14** is formed by coating a macromolecule solution or molten macromolecule material. The macromolecule solution is formed by dissolving a macromolecule material into an organic solvent. The organic solvent can be ethanol, methanol, acetone, or chloroform. The molten macromolecule material is formed by heating the macromolecule material to a molten temperature of the macromolecule material. The macromolecule solution or the molten macromolecule material can have a viscosity greater than 1 Pa·s. A melting point of the macromolecule material can be lower than or equal to 600° C., or a decomposing temperature of the macromolecule material can be lower than or equal to 600° C. In one embodiment, the melting point of the macromolecule material is lower than or equal to 300° C., or a decomposing temperature of the macromolecule material is lower than or equal to 300° C. The macromolecule material can be phenolic resin (PF), polystyrene (PS), ethoxyline resin (EP), polyurethane (PU), polymethyl methacrylate (PMMA), polycarbonate (PC), polyethylene terephthalate (PET), or polyalkenamer.

[0048] The macromolecule solution or the molten macromolecule material can be uniformly coated on the surface of the single walled carbon nanotube film **12** by a spraying method, or a spin coating method. The surface of the single walled carbon nanotube film **12** away from the substrate **10** can be immersed in the macromolecule solution. It is necessary to make sure the macromolecule material layer **14** cover each of the plurality of SWCNTs. A thickness of the macromolecule material layer **14** is related to the distance between two adjacent SWCNTs. The thickness of the macromolecule material layer **14** can be in a range from about 0.1 micrometers to about 1 millimeter. In one embodiment, the macromolecule material is PMMA, and the organic solvent is methylphenoxide.

[0049] In the step (S**4**), the macromolecule material layer **14** barely absorbs electromagnetic wave energy. A heat capacity per unit area of the macromolecule material layer **14** is greater than the heat capacity per unit area of the single walled carbon nanotube film **12**. The semiconducting SWCNTs **124** barely absorb the electromagnetic wave energy, but the metallic SWCNTs **122** can absorb the electromagnetic wave energy and generate heat. That is, a speed of absorbing the electromagnetic wave energy of the metallic SWCNTs **122** is faster than the speed of absorbing the electromagnetic wave energy of the semiconducting SWCNTs **124**. Thus, after absorbing the electromagnetic wave energy, a temperature of the metallic SWCNTs **122** rises quickly. This temperature increase will heat the portions of the macromolecule material layer **14** covering the metallic SWCNTs **122** until the macromolecule material layer **14** is melted or decomposed. The metallic SWCNTs **122** are exposed because the portions of the macromolecule material layer **14** covering the metallic SWCNTs **122** is melted or decomposed.

[0050] At the same time, the heat generated by the metallic SWCNTs **122** can be absorbed by the macromolecule material layer **14** and the substrate **10**. Thus, the temperature of the single walled carbon nanotube film **12** can be controlled to be under 700° C., and the single walled carbon nanotube film **12** will not burn.

[0051] The semiconducting SWCNTs **124** barely absorbs the electromagnetic wave energy, so the temperature of the portion of the macromolecule material layer **14** covering the semiconducting SWCNTs **124** dose not rise. The portions of the macromolecule material layer **14** covering the semiconducting SWCNTs **124** are not melted or decomposed. Thus, the semiconducting SWCNTs **124** are still covered by the macromolecule material layer **14**.

[0052] In one embodiment, the thickness of the macromolecule material layer **14** is less than the distance between two adjacent SWCNTs, in order to expose the metallic SWCNTs

122 but not burn out their adjacent semiconducting SWCNTs **124**. In one embodiment, the thickness of the macromolecule material layer **14** is in a range from about 10 nanometers to about 500 nanometers, the temperature of the portions of the macromolecule material layer **14** covering the metallic SWCNTs **122** is raised to 300 degrees.

[0053] A power of the electromagnetic waves can be in a range from about 300 watts to about 2000 watts. A frequency of the electromagnetic waves can be in a range from about 0.3 gigahertz to about 1×10^{6} gigahertz. The electromagnetic waves can be radio frequency, microwaves, near infrared, or far infrared. In one embodiment, the electromagnetic waves are microwaves. A power of the microwaves can be in a range from about 300 watts to about 1500 watts. A frequency of the microwaves can be in a range from about 0.3 gigahertz to about 300 gigahertz. The compound is kept in a chamber filled with the microwaves from about 1 second to about 600 seconds. In other embodiments, the compound is kept in the chamber filled with the microwaves from about 3 seconds to about 90 seconds. The time period the compound is kept in the chamber filled with the microwaves depends on the macromolecule material layer **14** and the power of the microwaves. The higher the power of the microwaves, the shorter the time the chamber needs to be filled with the microwaves. In one embodiment, the time is about 30 seconds.

[0054] The step (S**4**) can be carried out in a vacuum environment or in a specific atmosphere of protective gases such as nitrogen gas or inert gases. A gas pressure of the environment is in a range from about 1×10^{-2} Pascals to about 1×10^{-6} Pascals. The single walled carbon nanotube film **12** can reach the temperature of about 900 degrees in the vacuum environment or in the specific atmosphere of protective gases.

[0055] In the step (S**5**), the metallic SWCNTs **122** can be removed by a reactive ion etching (RIE) method. A method of the RIE of one embodiment includes steps of:

[0056] (S**51**), disposing the macromolecule material layer **14**, the single walled carbon nanotube film **12** and the substrate **10** in a reactive ion etching vacuum chamber;

[0057] (S**52**), introducing reactive gas into the reactive ion etching vacuum chamber; and

[0058] (S**53**), etching away the metallic SWCNTs **122** by reactive ions generated by glow discharge of the reactive gas.

[0059] In the step (S**52**), the reactive gas can be oxygen, hydrogen, argon, ammonia, or CF_4. In one embodiment, the reactive gas is oxygen gas.

[0060] In the step (S**53**), during the etching process, the reactive ions etch away the metallic SWCNTs **122**. A power of the RIE system can be in a range from about 20 watts to about 300 watts. A flow rate of the reactive gas can be in a range from about 10 sccm to about 100 sccm. An etching period can be in a range from about 5 seconds to about 10 minutes. In one embodiment, the power of the RIE system is about 30 watts, the flow rate of the reactive gas is about 50 sccm, and the etching period is in a range from about 15 seconds to about 1 minute.

[0061] In the step (S**6**), the macromolecule material layer **14** can be removed by a chemical reagent. The chemical reagent can be tetrahydrofuran, dichloroethane, chloroform, acetone, glacial acetic acid, dioxane, tetrahydrofuran, acetic ether, or toluene. In one embodiment, the macromolecule material layer **14** is immersed into the acetone to remove the macromolecule material layer **14**, wherein the macromolecule material layer **14** is made of PMMA. Furthermore, the semiconducting SWCNTs **124** located on the first surface **102** of the substrate **10** can be taken out from the chemical reagent and dried.

[0062] Referring to FIGS. **1** and **5**, a method for making semiconducting SWCNTs of another embodiment includes steps of:

[0063] (S**1**), providing a substrate **10** having a first surface **102**;

[0064] (S**2**), placing a single walled carbon nanotube film **12** on the first surface **102** of the substrate **10**, wherein the single walled carbon nanotube film **12** includes a plurality of metallic SWCNTs **122** and a plurality of semiconducting SWCNTs **124**;

[0065] (S**3**), applying at least one electrode **16** on one side of the single walled carbon nanotube film **12** and electrically connecting with the single walled carbon nanotube film **12**;

[0066] (S**4**), forming a macromolecule material layer **14** on the single walled carbon nanotube film **12** to cover each of the plurality of metallic SWCNTs **122** and each of the semiconducting SWCNTs **124**;

[0067] (S**5**), exposing the plurality of metallic SWCNTs **122** by bombarding the macromolecule material layer **14** with an electron beam;

[0068] (S**6**), removing the plurality of metallic SWCNTs **122**; and

[0069] (S**7**), removing the macromolecule material layer **14** to obtain the plurality of semiconducting SWCNTs **124**.

[0070] The step (S**1**) where the melting point of the substrate **10** can be arbitrary.

[0071] In step (S**2**), two adjacent SWCNTs of the single walled carbon nanotube film **12** can be in contact with each other or be spaced from each other. The plurality of SWCNTs of the single walled carbon nanotube film **12** has the same length and be parallel to each other.

[0072] In the step (S**3**), the at least one electrode **16** can be located on one side of the single walled carbon nanotube film **12**. In one embodiment, two of the electrodes **16** are located on opposite two sides of the single walled carbon nanotube film **12**. The at least one electrode **16** is electrically connected to one end or two ends of the plurality of SWCNTs.

[0073] The electrode **16** can be made of conductive material, such as metal, conductive polymer, conductive adhesive, metallic carbon nanotubes, or indium tin oxide. The shape and structure of the electrode **16** is arbitrary. The electrodes **16** can be made by a method such as screen printing, chemical vapor deposition, or magnetron sputtering. In one embodiment, the electrode **16** is formed concurrently by printing conductive silver paste. The conductive silver paste can include about 50% to about 90% (by weight) of the metal powder, about 2% to about 10% (by weight) of the glass powder, and about 8% to about 40% (by weight) of the binder.

[0074] In the step (S**4**), the melting point of the macromolecule material layer **14** can be arbitrary. The macromolecule material layer **14** can be penetrated by a high-energy electron beam.

[0075] In the step (S**5**), an electron beam source is located above the macromolecule material layer **14**, and an electric field is supplied between the electron beam source and the macromolecule material layer **14**. The electron beam source can emit the high-energy electron beam including a plurality of electrons.

[0076] During the bombarding process, when the plurality of electrons from the electron beam source reaches to the semiconducting SWCNTs **124**, firstly the semiconducting

SWCNTs **124** will collect and gather the plurality of electrons. The plurality of electrons collected and gathered by the semiconducting SWCNTs **124** can form a protective layer to protect the semiconducting SWCNTs **124**. Then when some electrons form the electron beam source continue to reach to the semiconducting SWCNTs **124**, the electrons will be reflected by the protective layer to the metallic SWCNTs **122**.

[0077] When the electrons from the electron beam source and reflected by the protective layer reach to the metallic SWCNTs **122**, the electrons will be transmitted to the electrode **16** along an axial direction of each of the metallic SWCNTs **122** in the electric field. In the process of transmitting the electrons along the axial direction of each of the metallic SWCNTs **122** in the electric field, the portions of the macromolecule material layer **14** covering the metallic SWCNTs **122** will be etched, and the metallic SWCNTs **122** will be exposed. The semiconducting SWCNTs **124** are still covered by the macromolecule material layer **14**.

[0078] Energy of the high-energy electron beam from the electron beam source can be in a range from about 200 electron volts (eV) to about 200 kiloelectron volts (KeV). Electron beam bombarding time can be in a range from about 5 seconds to about 10 minutes. In one embodiment, the energy of the high-energy electron beam is in a range from about 500 eV to about 100 KeV, and the electron beam bombarding time is in a range from about 30 seconds to about 5 minutes.

[0079] In summary, in the process of making the semiconducting SWCNTs **124** by above-described methods, the metallic SWCNTs **122** can be completely removed, and the semiconducting SWCNTs **124** are not destroyed. Thus, the semiconducting SWCNTs **124** have high purity. Moreover, the method for making the semiconducting SWCNTs **124** is simple and can be mass produced in a large quantity.

[0080] It is to be understood that the above-described embodiment is intended to illustrate rather than limit the disclosure. Variations may be made to the embodiment without departing from the spirit of the disclosure as claimed. The above-described embodiments are intended to illustrate the scope of the disclosure and not restricted to the scope of the disclosure.

[0081] It is also to be understood that the above description and the claims drawn to a method may include some indication in reference to certain steps. However, the indication used is only to be viewed for identification purposes and not as a suggestion as to an order for the steps.

What is claimed is:

1. A semiconducting single walled carbon nanotubes (SWCNTs) making method comprising:

placing a single walled carbon nanotube film on a first surface of a substrate, wherein the single walled carbon nanotube film comprises a plurality of SWCNTs comprising metallic SWCNTs and semiconducting SWCNTs;

applying a macromolecule material layer on the single walled carbon nanotube film to cover the single walled carbon nanotube film, wherein the macromolecule material layer, the single walled carbon nanotube film and the substrate form a compound;

exposing the metallic SWCNTs by melting or decomposing portions of the macromolecule material layer covering the metallic SWCNTs in an environment of electromagnetic waves to obtain a treated compound;

removing the metallic SWCNTs; and

removing the macromolecule material layer.

2. The semiconducting SWCNTs making method of claim **1**, wherein adjacent SWCNTs of the plurality of SWCNTs are not in contact with each other, and a distance between the adjacent SWCNTs is greater than or equal to 10 nanometers.

3. The semiconducting SWCNTs making method of claim **1**, wherein the plurality of SWCNTs has a same length and are parallelly spaced from each other.

4. The semiconducting SWCNTs making method of claim **1**, wherein the single walled carbon nanotube film is a free-standing structure.

5. The semiconducting SWCNTs making method of claim **1**, wherein the plurality of SWCNTs have different lengths and are spaced from each other.

6. The semiconducting SWCNTs making method of claim **5**, wherein the placing the single walled carbon nanotube film on the first surface of the substrate comprises coating a solution of SWCNTs on the first surface of the substrate.

7. The semiconducting SWCNTs making method of claim **1**, wherein the plurality of SWCNTs is parallel to a surface of the single walled carbon nanotube film and the first surface of the substrate.

8. The semiconducting SWCNTs making method of claim **1**, wherein the melting or decomposing portions of the macromolecule material layer comprises heating the portions of the macromolecule material layer to a melting point greater than or equal to 600 degrees Celsius.

9. The semiconducting SWCNTs making method of claim **1**, wherein the applying the macromolecule material layer on the single walled carbon nanotube film comprises coating a macromolecule solution or molten macromolecule material.

10. The semiconducting SWCNTs making method of claim **1**, wherein applying the macromolecule material layer further comprises enclosing each of the metallic SWCNTs and each of the semiconducting SWCNTs.

11. The semiconducting SWCNTs making method of claim **1**, wherein applying the macromolecule material layer further comprises filling spaces between adjacent SWCNTs of the plurality of SWCNTs.

12. The semiconducting SWCNTs making method of claim **1**, wherein a thickness of the macromolecule material layer is in a range from about 0.1 micrometers to about 1 millimeter.

13. The semiconducting SWCNTs making method of claim **1**, wherein the exposing the metallic SWCNTs comprises exposing the compound to microwaves.

14. The semiconducting SWCNTs making method of claim **13**, wherein the exposing the compound to microwaves comprises keeping the compound in a chamber filled with the microwaves for about 3 seconds to about 90 seconds, a power of the microwaves is in a range from about 300 watts to about 1500 watts, and a frequency of the microwaves is in a range from about 0.3 gigahertz to about 300 gigahertz.

15. The semiconducting SWCNTs making method of claim **13**, wherein the compound is exposed to the microwaves for about 30 seconds.

16. The semiconducting SWCNTs making method of claim **1**, wherein the removing the metallic SWCNTs comprises steps of:

disposing the treated compound in a reactive ion etching vacuum chamber;

introducing reactive gas into the reactive ion etching vacuum chamber; and

etching away the metallic SWCNTs by reactive ions generated by glow discharging of the reactive gas.

17. The semiconducting SWCNTs making method of claim **1**, wherein the removing the macromolecule material layer comprises treating the macromolecule material layer with a chemical reagent.

18. A semiconducting single walled carbon nanotubes (SWCNTs) making method comprising:

placing a single walled carbon nanotube film on a first surface of a substrate, wherein the single walled carbon nanotube film comprises a plurality of SWCNTs comprising metallic SWCNTs and semiconducting SWCNTs, wherein the plurality of SWCNTs is parallel to each other;

applying a macromolecule material layer on the single walled carbon nanotube film to enclose the metallic SWCNTs and the semiconducting SWCNTs;

exposing the metallic SWCNTs by melting or decomposing portions of the macromolecule material layer covering the metallic SWCNTs in an environment of electromagnetic waves;

etching away the plurality of metallic SWCNTs; and

removing the macromolecule material layer.

19. The semiconducting SWCNTs making method of claim **18**, wherein a distance between adjacent SWCNTs of the plurality of SWCNTs is greater than or equal to 10 nanometers.

20. The semiconducting SWCNTs making method of claim **18**, wherein applying the macromolecule material layer further comprises filling spaces between adjacent SWCNTs of the plurality of SWCNTs.

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